The Detection of Lyα Absorption from Nine Nearby Galaxies

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We have used STIS aboard HST to search for Lyα absorption in the outer regions of nine nearby ($cz < 6000$ km s^{-1}) galaxies using background QSOs and AGN as probes. The foreground galaxies are intercepted between 26 and 199 h^{-1} kpc from their centers, and in all cases we detect Lyα within ± 500 km s^{-1} of the galaxies' systemic velocities. The intervening galaxies have a wide range of luminosities, from $M_B = -17.1$ to -20.0, and reside in various environments: half the galaxies are relatively isolated, the remainder form parts of groups or clusters of varying richness. The equivalent widths of the Lyα lines range from $0.08 - 0.68$ Å and, with the notable exception of absorption from one pair, correlate with sightline separation in a way consistent with previously published data, though the column densities derived from the lines do not. The lack of correlation between line strength and galaxy luminosity or, in particular, the environment of the galaxy suggests that the absorption is not related to any individual galaxy, but arises in gas which follows the same dark-matter structures that the galaxies inhabit.

1 Introduction

The detection of $z << 1$ Lyα-forest absorption lines in the spectra of QSOs observed by HST shortly after its launch [1,2,3] not only demonstrated the existence and evolution of these tenuous neutral hydrogen (H I) clouds over a significant fraction of the age of the universe, but quickly sparked an interest as to whether it might be possible to establish the origin of the clouds themselves. Although generally thought to be intergalactic at high redshift (because of their high rate of incidence along a sightline, and their weak clustering [4]) the remarkable success at detecting galaxies responsible for the higher H I column density Mg II systems at low redshift [5,6,7] supported the case for investigating whether Lyα absorption lines might also arise in the halos of individual galaxies.

Mapping the galaxies around the sightline towards 3C 273 [8,9] produced little evidence for a direct association between individual galaxies and Lyα-absorbers. Morris et al. [9] concluded that Lyα clouds were not distributed at

random with respect to galaxies, nor did they cluster as strongly as galaxies cluster with each other, and could only be associated with galaxies on scales of $\sim 0.5-1$ Mpc. However, in a study of six different fields, Lanzetta et al.[10] found that *a*) the majority of normal, luminous galaxies possess extended Lyα-absorbing halos or disks of radii $\sim 160\ h^{-1}$ kpc, and *b*) between one and two thirds of all Lyα lines arise in such galaxies. Combined with other similar studies[11,12] it appeared that these disparate results might be reconciled if strong Lyα lines were associated with galaxies, while weak ones arose mainly in the intergalactic medium.

These initial results were soon re-evaluated in light of the rapid development in hydrodynamical and semi-analytic simulations of how gas behaves in hierarchical cold dark-matter structure formation. These simulations showed that gas should follow the same density fluctuations that are gravitationally induced by the dark matter distributions, resulting in a 'web' of intersecting filaments and sheets of gas. Analysis of artificial spectra, generated by shooting random sightlines through the simulations, were extremely successful in reproducing the observed properties of the high-redshift Lyα-forest[13,14,15,16,17]. In particular, they showed that low column density lines are produced predominantly in the filaments, while the higher column density lines arise from denser gas in a virialized halo, i.e., the same regions in which a high galaxy density might be expected.

As the theoretical work continues, Chen et al. (hereafter CLWB)[18] have now extended the original work of Lanzetta et al. and continue to find evidence for direct galaxy-absorber association. They also find that the strength of the absorption depends not only on impact parameter but also on galaxy luminosity, suggesting a stronger link between galaxy and absorber. Ortiz-Gil et al.[19] have associated *individual* components within a complex Lyα system with *individual* galaxies from a group towards Q1545+2101, instead of an intragroup medium (although the Lyα lines are at the same redshift as the QSO, so are not drawn from the same population as the lines normally analyzed). The simulators have also advanced their models to $z \sim 0$, and have again been able to reproduce many features of the observed Lyα-forest[?,21]. Davé et al.[22] have used an algorithm designed to identify clumps of gas and stars in their simulations which are likely to correspond to galaxies, and impressively, have been able to reproduce the correlation of line strength and impact parameter.

In a previous paper[23] we used Archival HST FOS data to search for Lyα lines from present-day galaxies in order to better understand whether Lyα absorption arises in the halos of individual galaxies. We found that, for lines stronger than 0.3 Å, *a*) nearby galaxies do not possess Lyα-absorbing halos beyond 300 h^{-1} kpc in radius, and *b*) the covering factor of galaxies

Table 1: Probes observed by HST to search for Lyα absorption from foreground galaxies.

Probe	Intervening Galaxy	$v_{\rm gal}$ (km s^{-1})	sep (h^{-1} kpc)	M_B- $5\log h$	W (Å)
Mrk 1048	NGC 988	1504	158	-20.0	0.11 ± 0.01
PKS 1004+130	UGC 5454	2792	84	-17.9	0.68 ± 0.05
ESO 438−G009	UGCA 226	1507	110	-17.1	0.36 ± 0.06
MCG+10−16−111	NGC 3613	1987	26	-19.8	0.54 ± 0.02
	NGC 3619	1542	85	-18.5	0.59 ± 0.02
PG 1149−110	NGC 3942	3696	92	-19.1	0.40 ± 0.06
Q1341+258	G1341+2555	5802	31	-18.0	0.08 ± 0.02
Q1831+731	NGC 6654	1821	143	-18.9	0.11 ± 0.02
	NGC 6654A	1558	199	-18.5	0.10 ± 0.01

between 50 and 300 h^{-1} kpc is ~ 40 %. However, we found no correlation of Lyα equivalent width with impact parameter or with galaxy luminosity, and questioned whether the galaxies were indeed responsible for the absorption lines. We instead concluded that our results supported the picture emerging at the time that Lyα lines arise in the sheets and filaments discussed above.

Our analysis suffered from two major deficiencies, namely that we probed few galaxies within the canonical 160 h^{-1} kpc, and that we were restricted to looking only for strong lines in the low resolution FOS data. We sought to remedy these deficiencies by obtaining more data with the STIS aboard HST, aiming to search for *weak* lines *within* 160 h^{-1} kpc of a nearby galaxy using the G140M grating. In this contribution, we outline some of the results obtained from that program. The experiment is not designed to address the origin of *all* Lyα absorbers, since we start by identifying a suitable galaxy and then search for absorption from that galaxy. We do not seek to establish what fraction of Lyα absorbers arise in galaxy halos.

2 HST Observations

In order to produce a sample of QSO-galaxy pairs which could be observed with HST, we cross-correlated the Third Reference Catalogue of Bright Galaxies[24] with version 7 of the QSO/AGN catalog of Véron-Cetty & Véron (1996). We chose galaxies with velocities > 1300 km s^{-1}, since absorption below these values would likely be lost in the damped Lyα absorption profile from the Milky Way. The final group of QSO-galaxy pairs successfully observed by HST is listed in Table 1. Half of the galaxies are relatively isolated, while the other half are found in groups of various richness. In Figures 1 & 2 we show

two examples of the fields studied, the poor group towards PKS 1004+130 and the rich group towards MCG+10−16−111. In Figure 3 we show three representative spectra: two are of the QSOs shown in the first two figures, while the third is of Q1341+258 which probes the halo of G1341+2555 at the small separation of 31 h^{-1} kpc.

We detect Lyα lines within a few hundred km s^{-1} from all nine galaxies. This suggests that galaxies in the local universe are indeed surrounded by low column density H I with $\log N(\mathrm{H\ I}) \sim 13-15$ at radii of $26-200\ h^{-1}$ kpc. The ubiquity of the detections suggests a high covering factor — ~ 100 % at these column densities and radii. A plot of equivalent width versus impact parameter shows a weak correlation (not shown herein), consistent with CLWB's results, although column density vs. impact parameter is uncorrelated. There also appears to be no dependency of line strength with any other parameters such as galaxy magnitude or morphology.

The question remains, therefore, whether the neutral hydrogen detected has anything to do with the galaxy itself. In light of the success that the hydrodynamical simulations have had embedding galaxies in sheets of H I (§1), does the detection of gas near a galaxy reflect anything more than the fact that gas and galaxy share the same gravitational potential? Our data show little evidence for individual galaxies producing or influencing the halos around themselves: for example, the detection of at least five individual Lyα components towards PKS 1004+130 at the velocity of UGC 5454 and a companion Low Surface Brightness galaxy LSBC D637−18 (Fig. 1), spanning 740 km s^{-1}, is hard to understand as arising in two overlapping halos 84 and 138 h^{-1} kpc from the QSO sightline. On the other hand, intragroup gas could be expected to show a broad velocity spread due to the velocity dispersion of the group. Further, the detection of weak absorption from the isolated galaxy G1341+2555 towards Q1341+258 (Fig. 3, bottom panel) when the impact parameter is only 31 h^{-1} kpc is very rare—there are no such cases of such small values of equivalent width for such a small impact parameter in CLWB's sample. Finally, the strong Lyα lines detected towards MCG+10−16−111 (Fig. 2) are coincident in velocity with a strong over-density of galaxies within 2 h^{-1} Mpc of the sightline, again suggesting that intragroup gas is probably responsible for the absorption. It seems likely therefore that the H I we detect—and indeed, the galaxies we chose to probe—both reflect the underlying gravitational fluctuations, as the simulations predict.

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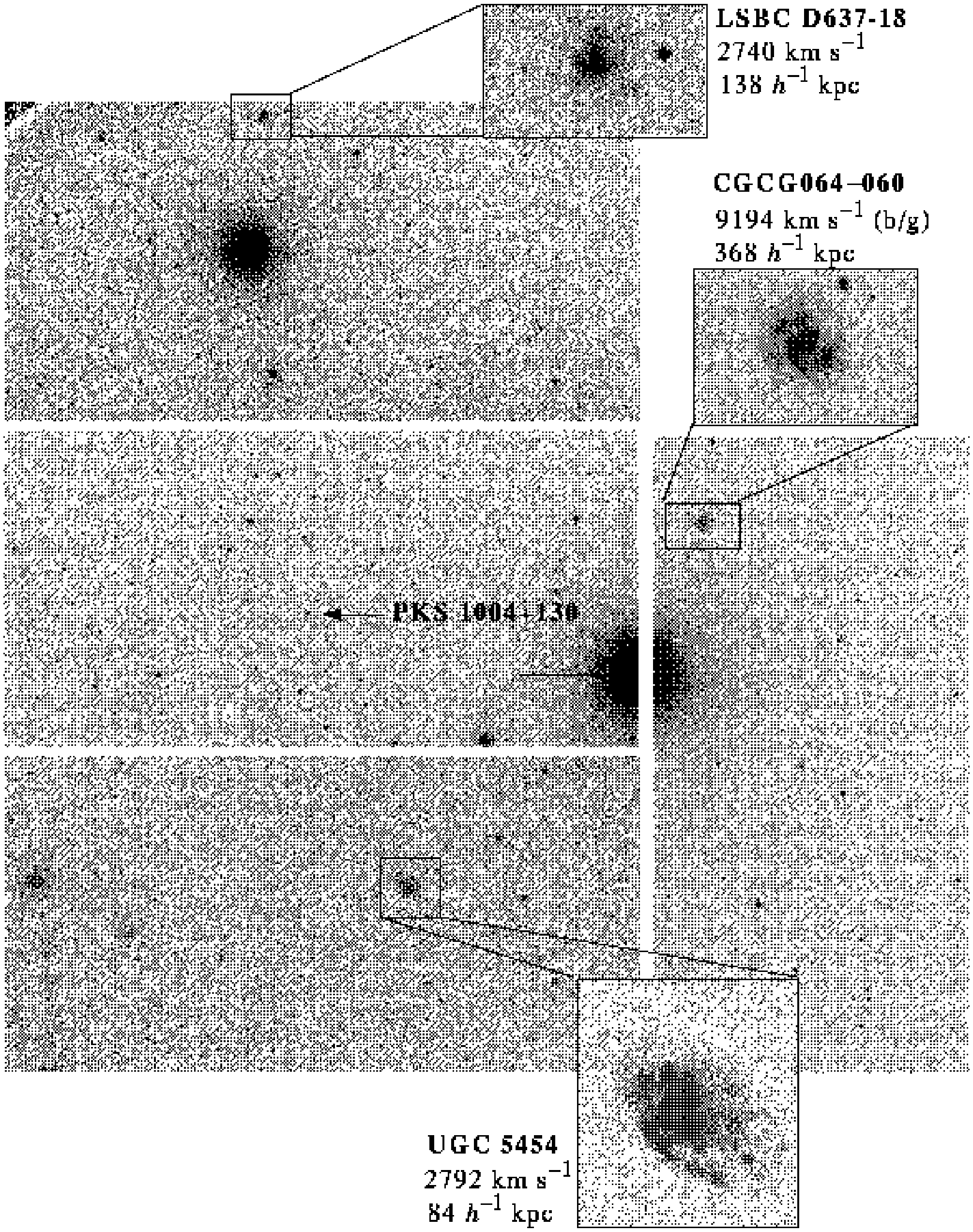

Figure 1: Reproduction of an Isaac Newton Telescope *Wide Field Camera* image of the field around the QSO PKS 1004+130 ($z = 0.240$). The field contains the dwarf galaxy UGC 5454 and an LSB galaxy LSBC D637−18. Below each designation, the galaxy's velocity and separation from the QSO sightline is given. For scale, the separation between the QSO and UGC 5454 is 10.5 arcmins. Lyα absorption is found to arise at the velocity of UGC 5454 & LSBC D637−18 (Fig. 3). The absorption is complex, consisting of at least five individual components, spanning a velocity interval of 740 km s^{-1}. Such strong & complex absorption is unlikely to arise from the halo of UGC 5454 & LSBC D637−18 alone, but probably from intragroup gas.

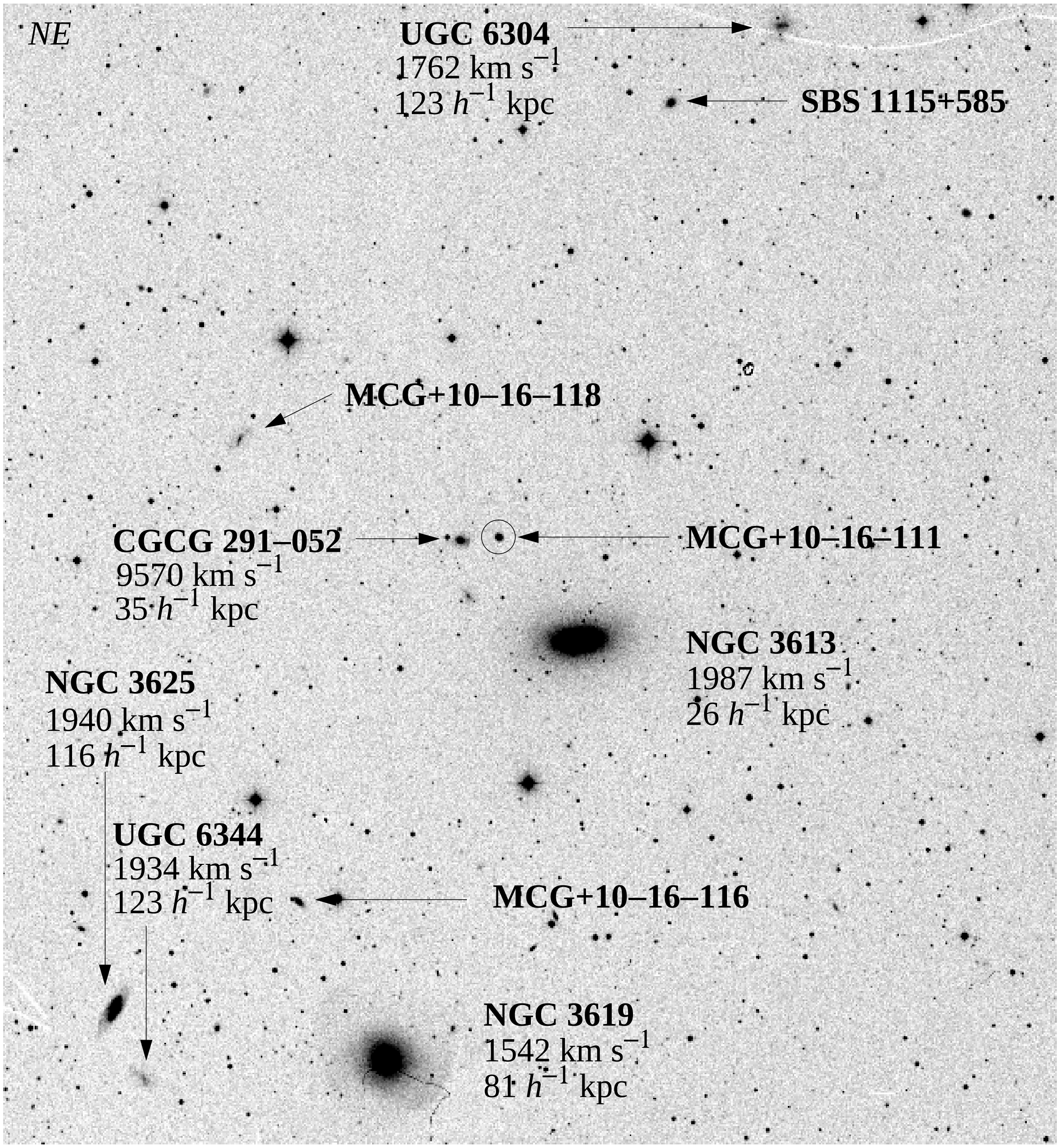

Figure 2: Reproduction of the STScI Digitized Sky Survey centered around MCG+10−16−111 ($z = 0.027$). The field is dominated by two bright galaxies, NGC 3613 & NGC 3619, although many fainter galaxies lie within radii of less than 150 h^{-1} kpc. Below each designation, the galaxy's velocity and separation from the probe's sightline is again given, although redshifts are not available for all galaxies identified. For scale, the separation between the MCG+10−16−111 (circled) and NGC 3619 is 18.2 arcmins. Strong Lyα absorption is detected at velocities of many of these galaxies (Fig. 3), although whether a single galaxy gives rise to the absorption is unclear.

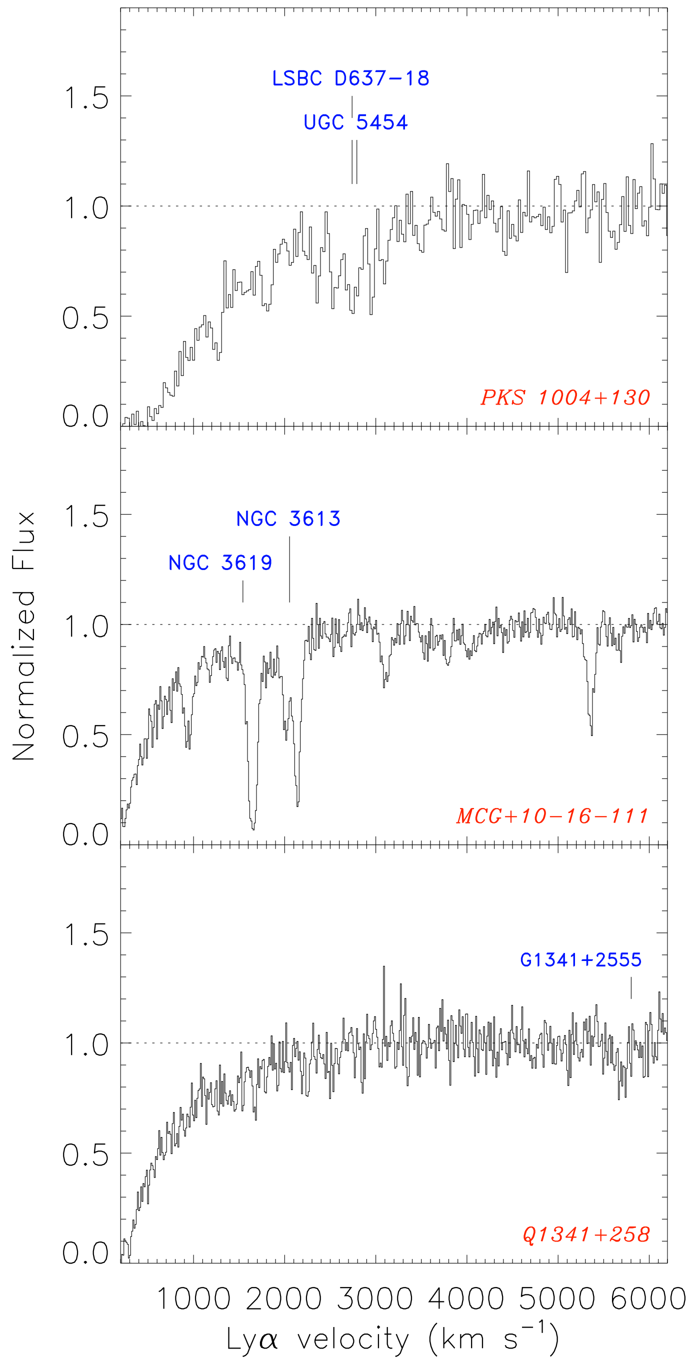

Figure 3: Three HST spectra from our survey. The strong decrease in flux at $v < 1000$ km s^{-1} is due to the damped Lyα profile arising from absorption by Milky Way H I. Velocities of the galaxies close to the probe sightline are labeled. The first two spectra show the absorption from galaxies in the fields presented in Figs. 1 & 2. The spectrum of PKS 1004+130 is binned 2x that of the other spectra due to its low S/N. The third spectrum shows extremely weak absorption towards Q1341+258 from a foreground galaxy only 31 h^{-1} kpc from the sightline. (The line may be blended with Galactic N V λ1238, which would make the intrinsic strength of the Lyα line even weaker.) Such weak absorption so close to a galaxy is extremely unusual compared to the equivalent widths found for galaxies at similar separations by CLWB.

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